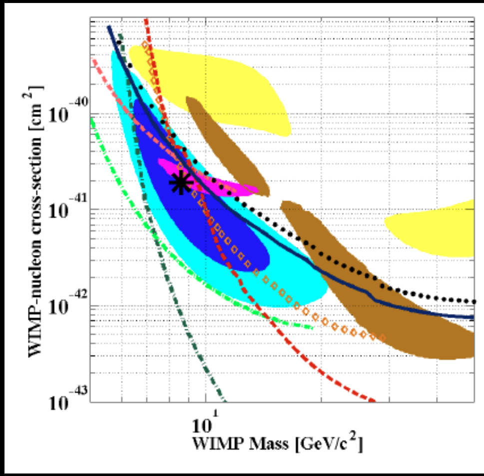
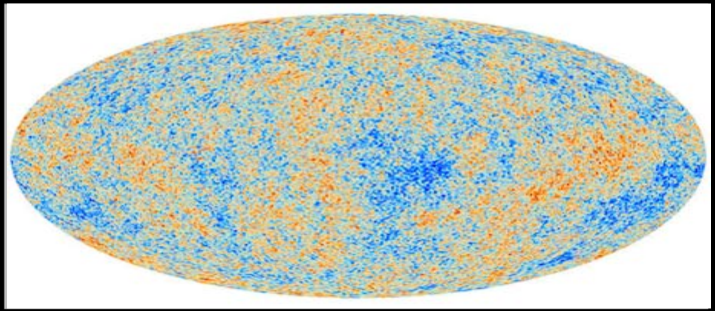
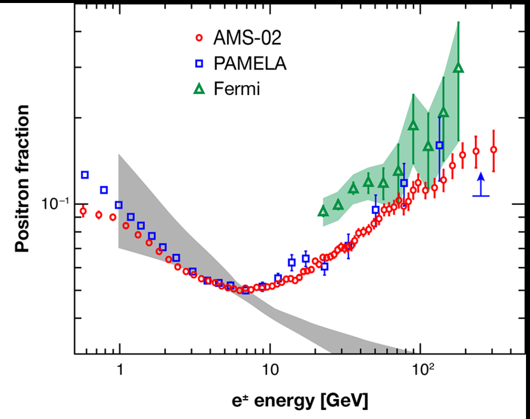
View from the Cosmic Frontier

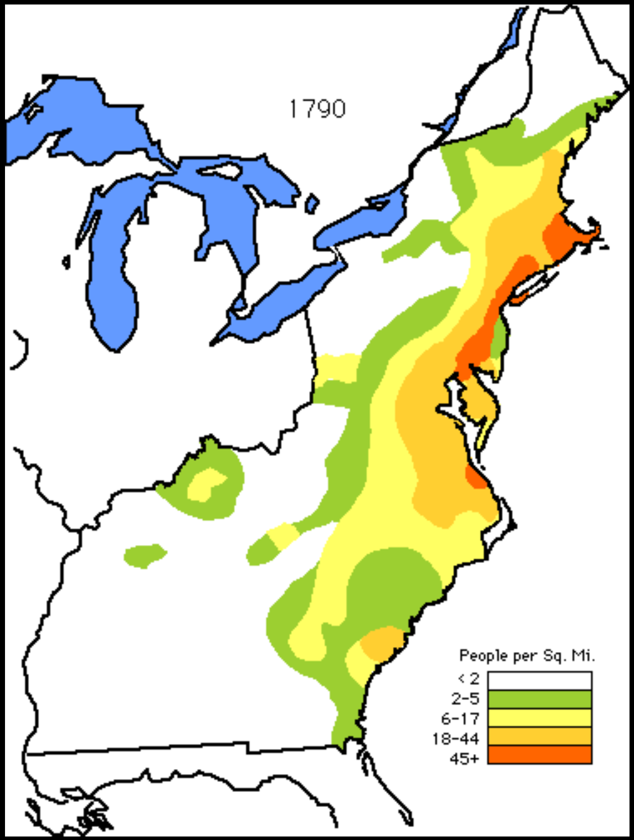






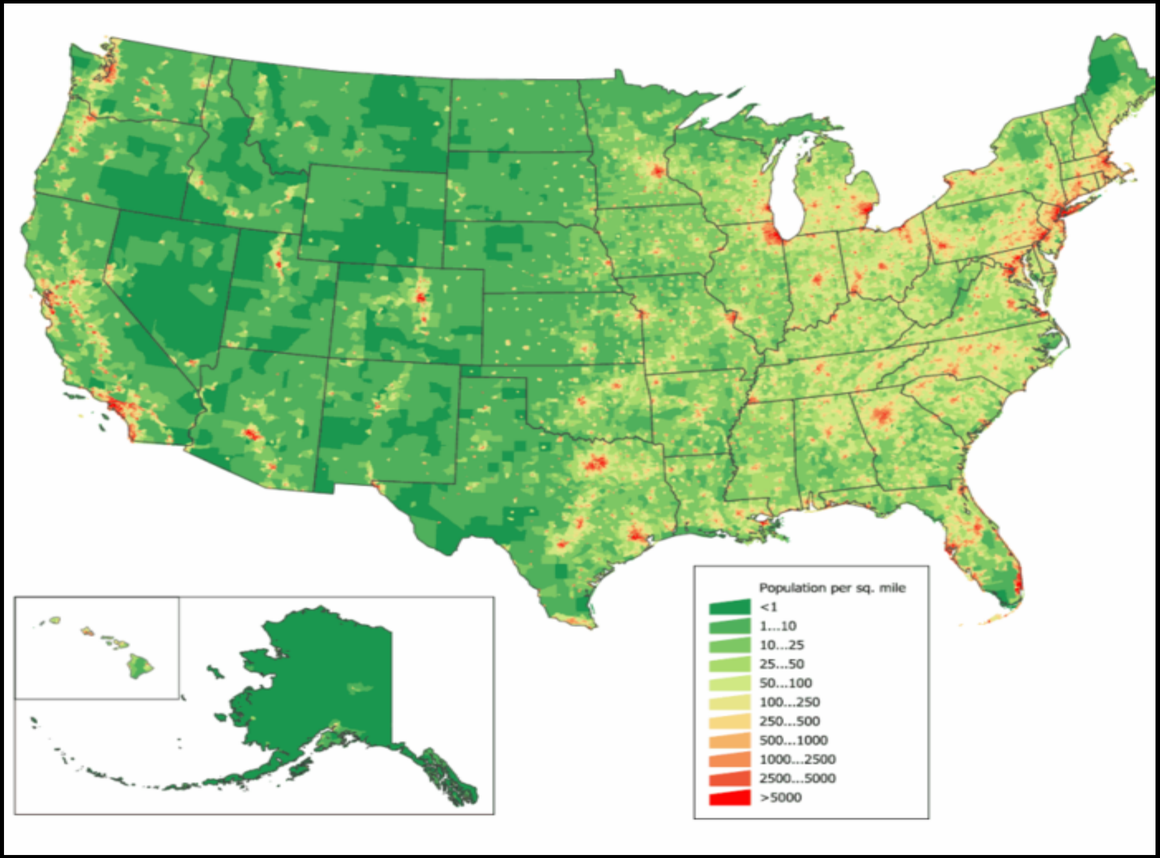
Consider the United States in 1790

- Over-densities of order 50
- Concentrated in East
- Vast Voids with low density

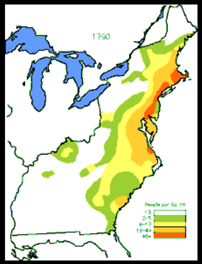


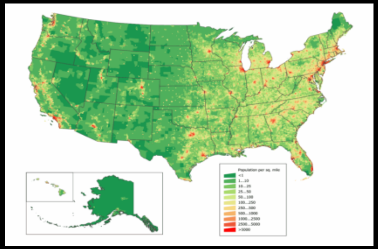
Consider the United States Today

- Over-densities of order 10,000
- Concentration in coasts
- Traces of *primordial* density (Boston-Washington; East > West)
- Vast Voids



The story of this evolution is the story of the United States

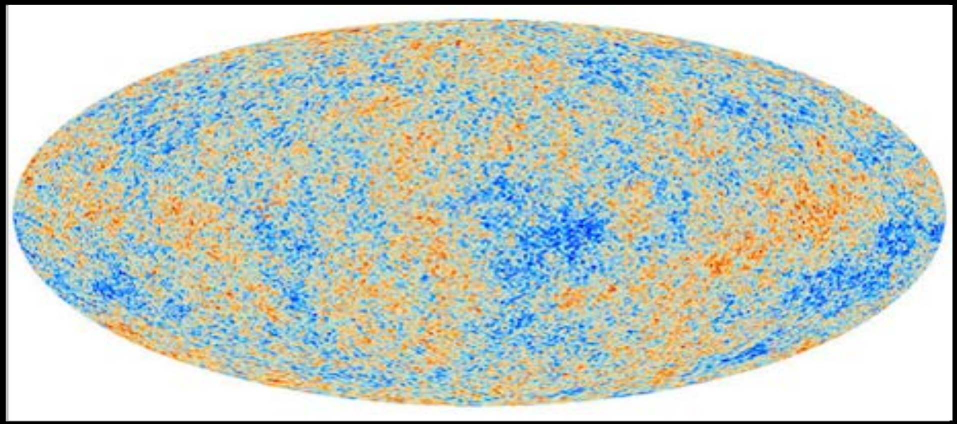




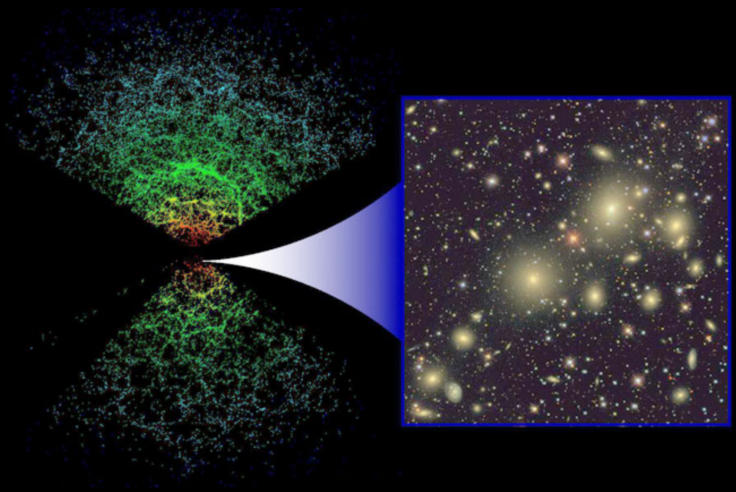
When we understand the evolution from one map to another, we can understand

- the sociological, economic, and political ***forces*** acting on the US
- the people, or the ***constituents****, of the US*

Less Parochially …



t = 400,000 years



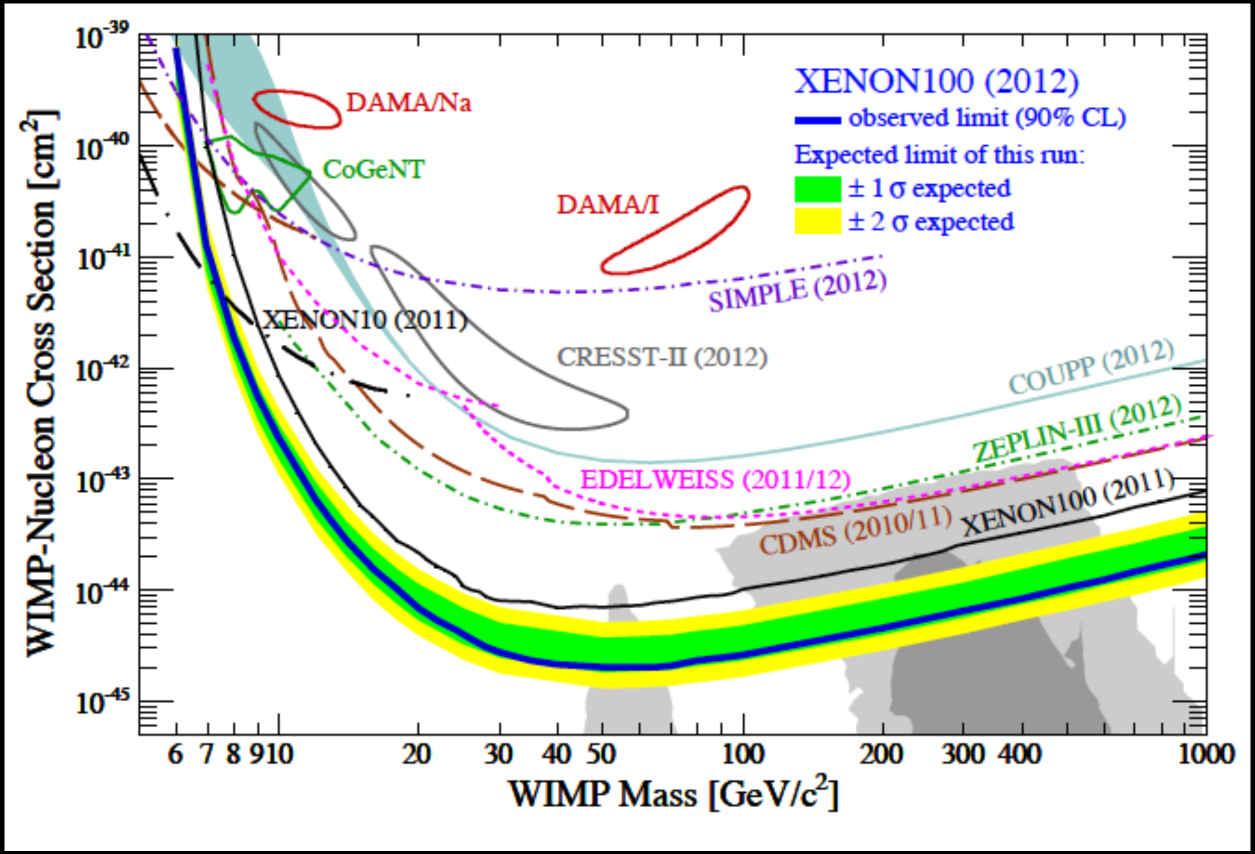
Today: Sloan Digital Sky Survey

Three epochs, each dominated by new physics, are required to explain the maps

- $t \sim 10^{-35}$ sec: Inflation, triggered by ***Early Dark Energy***
- 300,000 years < t < 7.7 Byrs: Growth of Structure, fueled by ***Dark Matter***
- t > 7.7 Byrs: Acceleration, caused by ***Dark Energy***

Dark Matter: Direct Detection

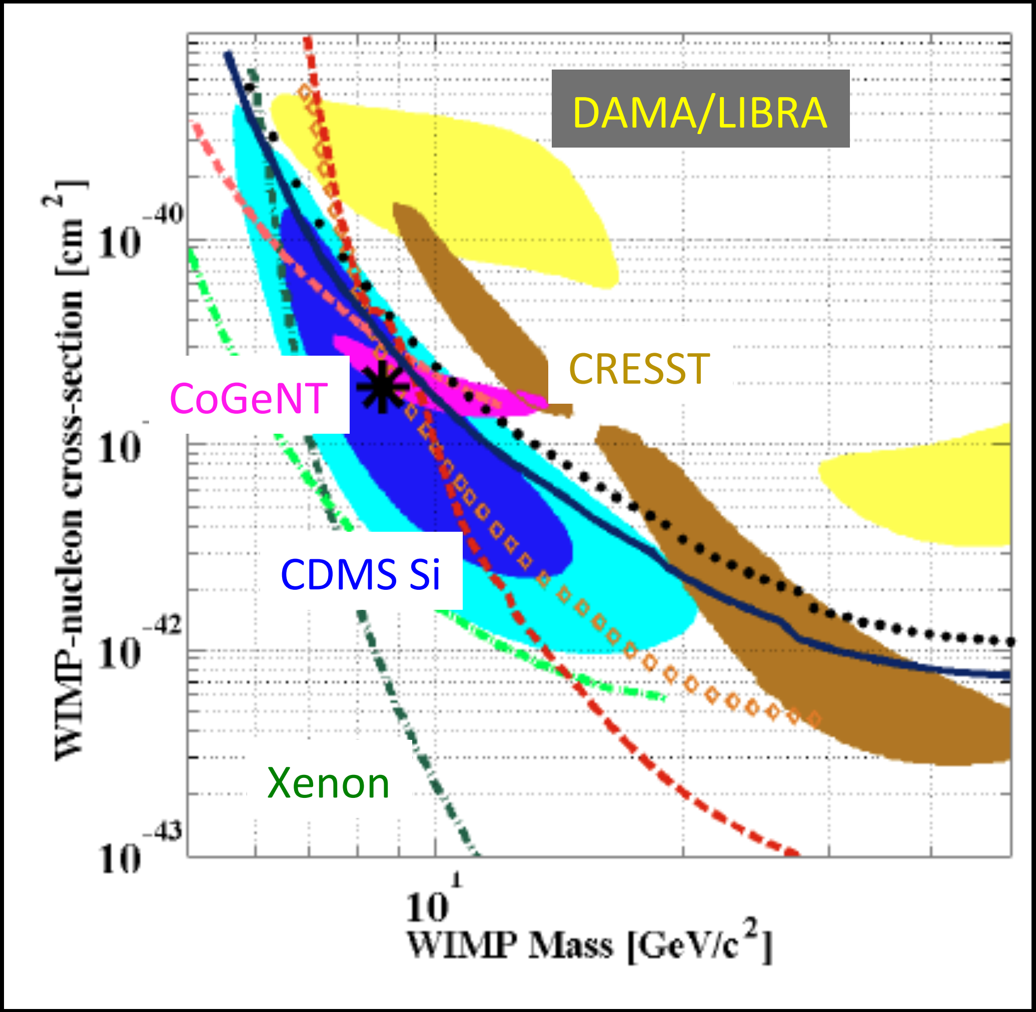
Starting to push into SUSY regime at high mass …



Aprile et al. 2012

Dark Matter: Direct Detection

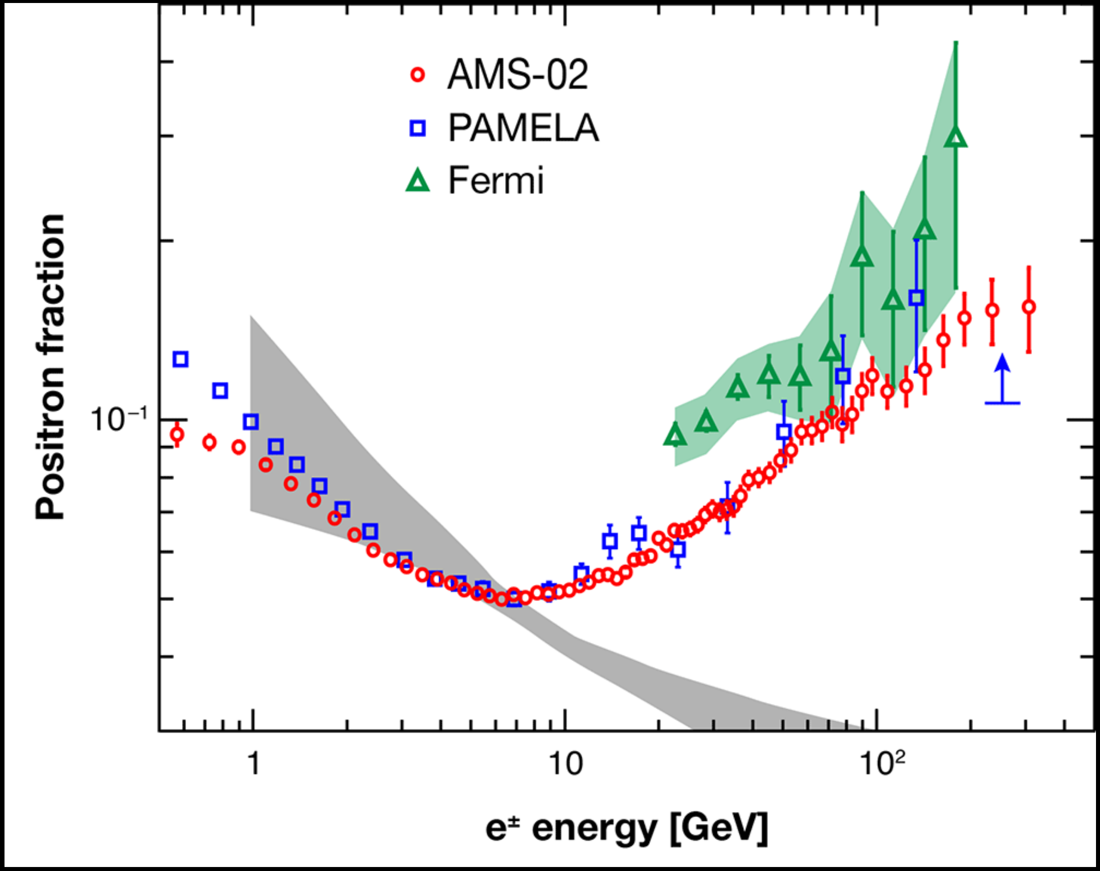
and several hints for detection at low mass → complementarity of different detection schemes important



Agnese et al.; April 15, 2013

Dark Matter: Indirect Detection

Several hints from positron excess (PAMELA, Fermi, AMS) and gamma rays from in and around Galactic center (Fermi)→ complementarity of different detectors important



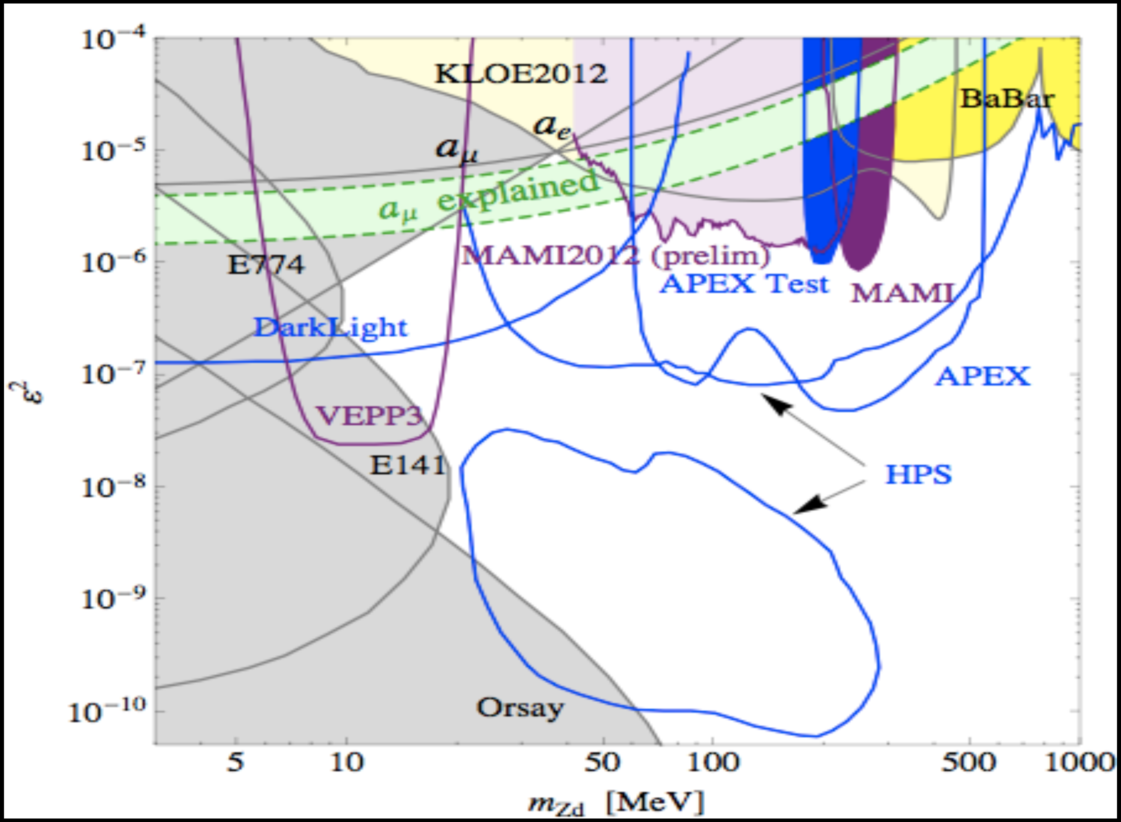
Aguilar et al. 2013

If DM is convincingly detected, it will further motivate laboratory experiments

To explain positron excess with dark matter annihilation, require:

- Sommerfeld enhancement (thermal freeze-out cross-section too low)
- No protons– anti-protons produced in annihilation

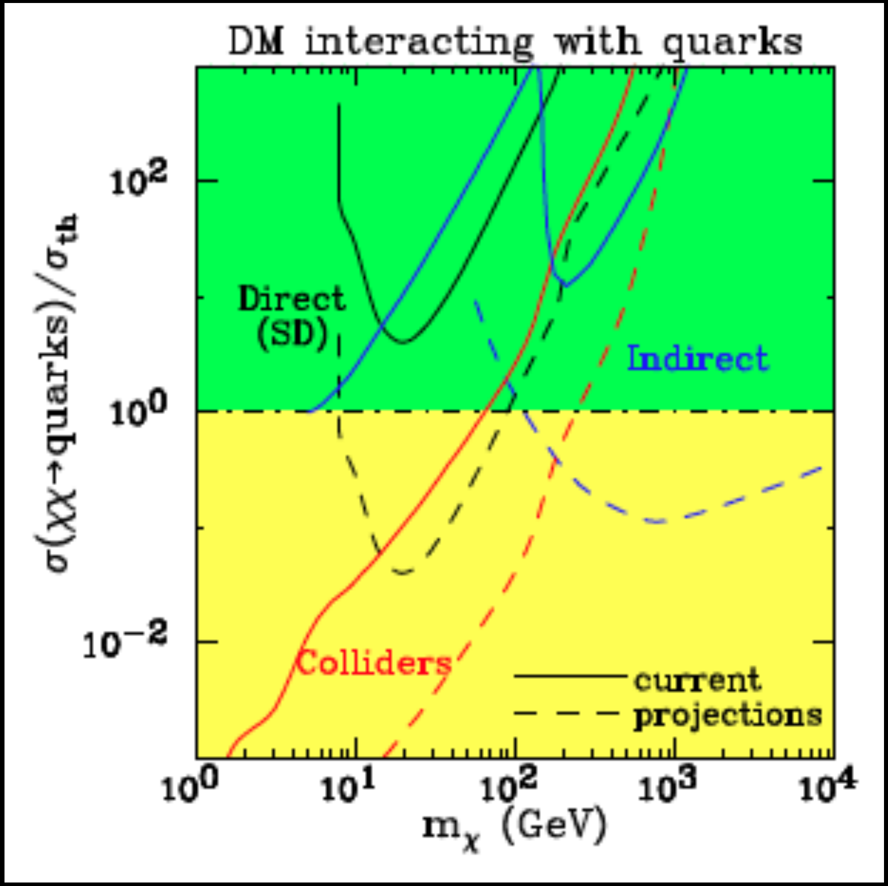
→* Light, Dark Photons



* Controversy how easy to get Sommerfeld enhancement

Dark Matter Complementarity

"…complementarity of the four general approaches (direct, indirect, collider, astrophysical) that are required to sustain a vital dark matter research program"



http://www.snowmass2013.org/tiki-view_forum.php?forumId=10

What (besides Lambda) could be driving the acceleration of the Universe?

Quintessence: New dynamical field with small mass

Test this by measuring the equation of state of dark energy (w,w’) with four probes:

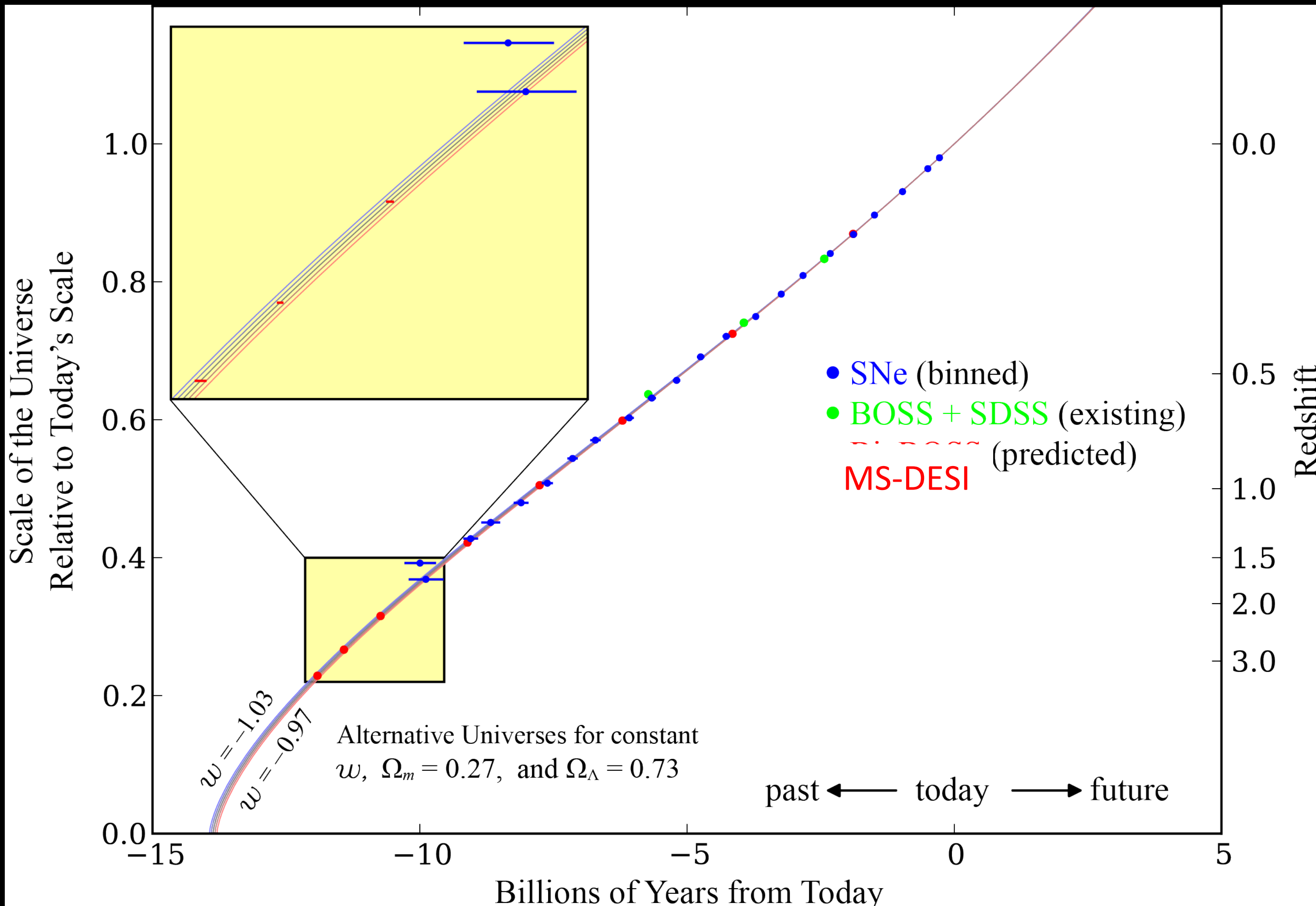
Supernovae

Baryon Acoustic Oscillations

Galaxy Clusters

Gravitational Lensing

Exciting Program to Extend Distance Measurements



Maybe Einstein was wrong

Modified Gravity

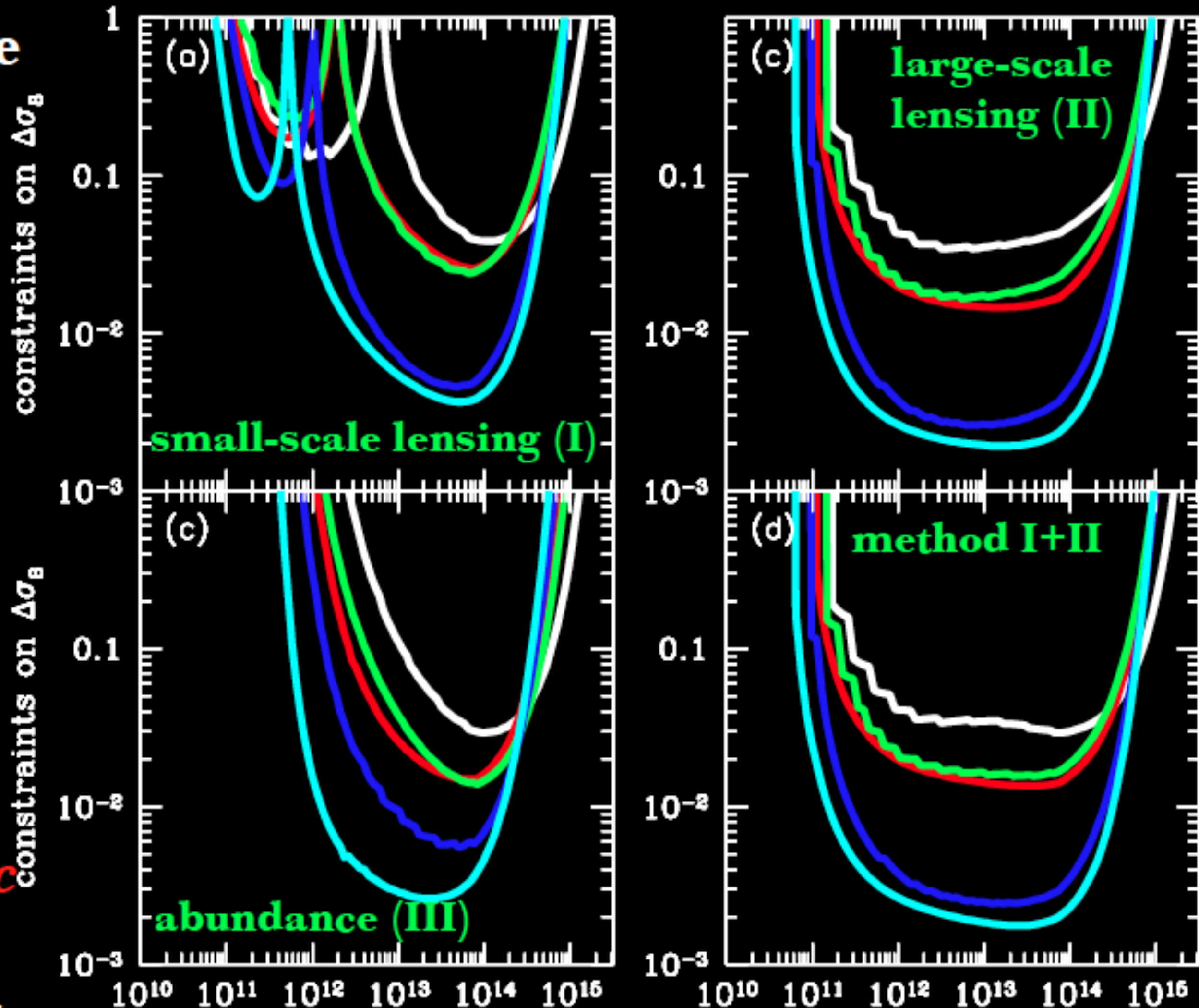
$$S \neq \frac{1}{16\pi G}\int d^4x\sqrt{-g}R + \int d^4x\sqrt{-g}L_m$$

Distance/redshift relationship (``zero order cosmology") can be accommodated in MG models. Growth of structure differs in MG and DE models.

Measure growth of structure by combining probes

- **abundance method (III) is powerful**
- **lensing + clustering (I+II) is equally powerful**
- ***systematic* can be important**

III. FUTURE GALAXY SURVEYS

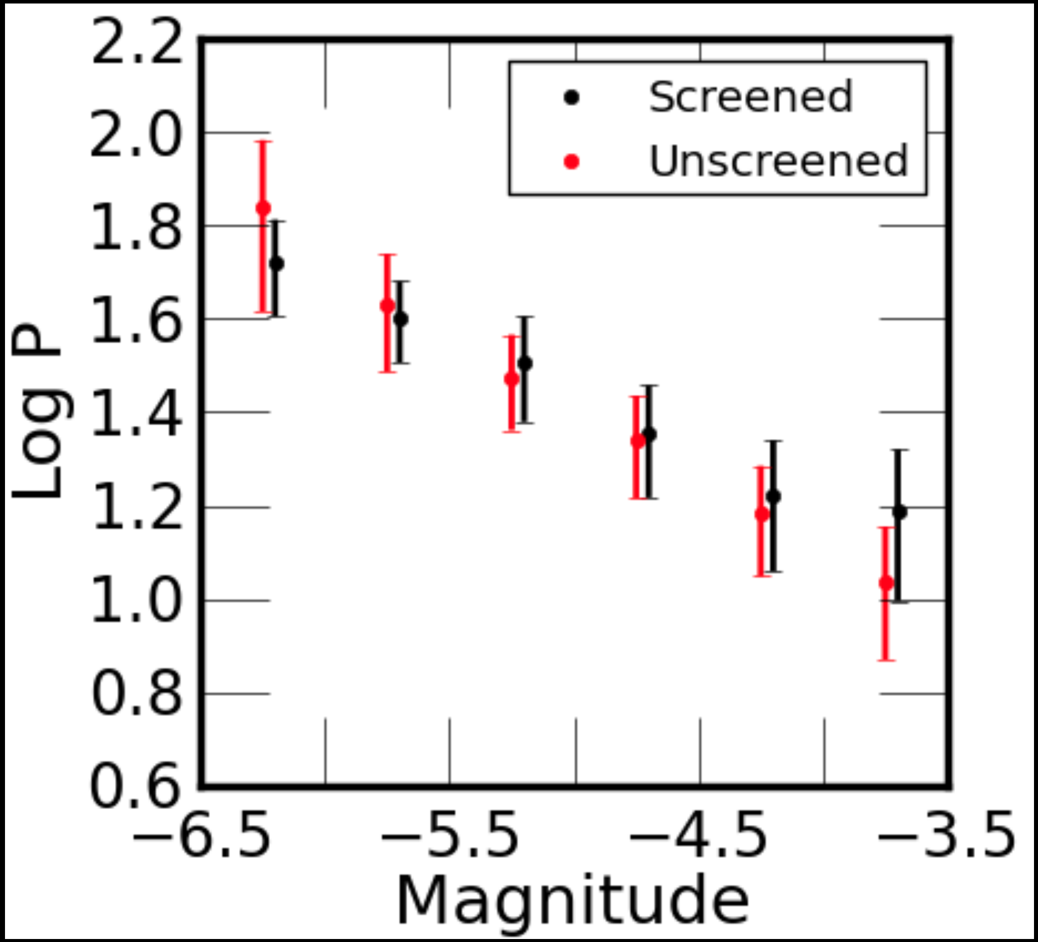


SDSS, DES, Euclid, LSST

Yoo

Non-cosmological tests of MG

MG models introduce extra degree of freedom, leading to enhanced gravitational force. This needs to be screened in regions of high density to pass solar system tests



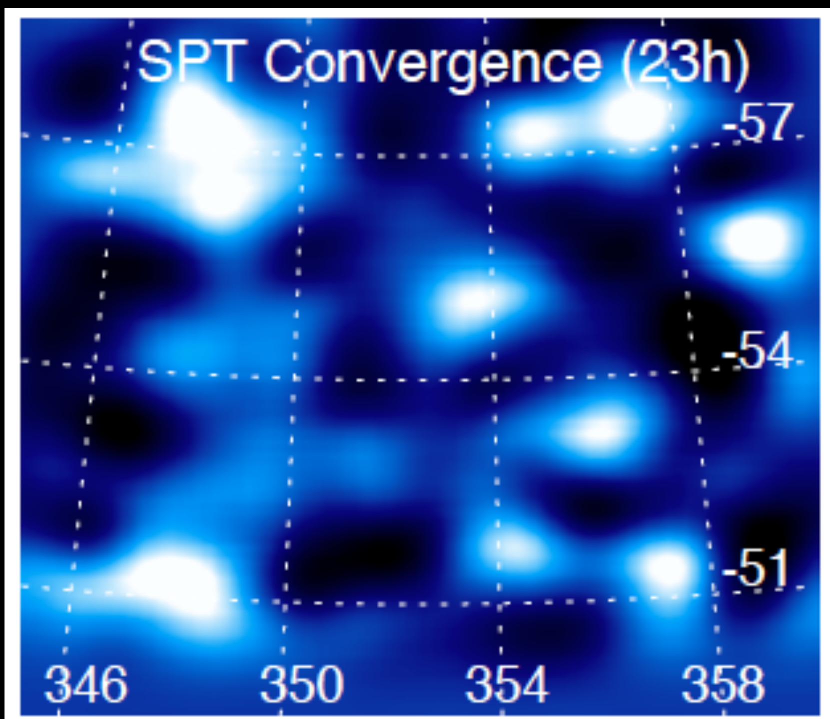
Jain

Is Dark Energy a new phenomenon?

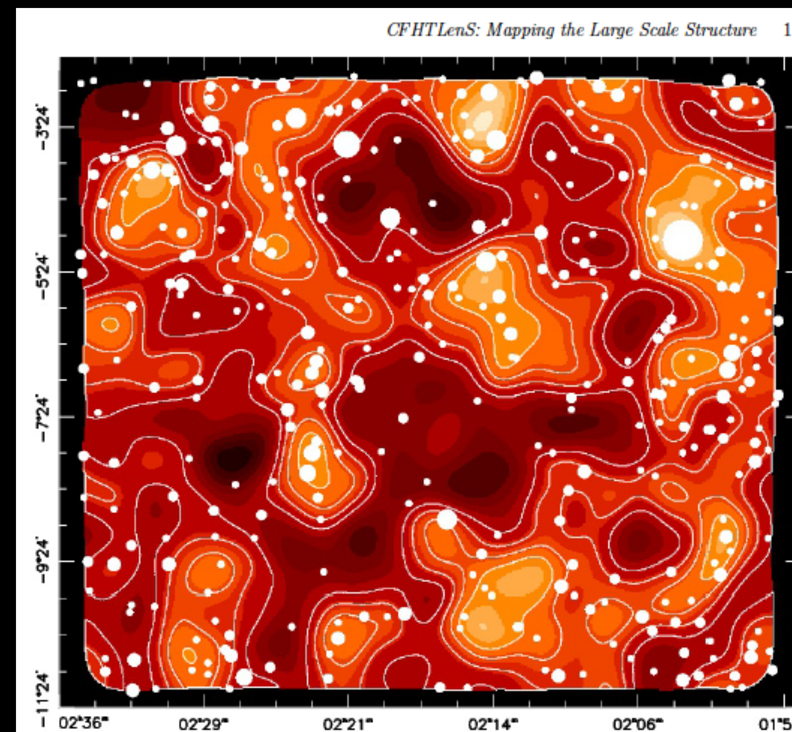
Inflation was an early epoch of dark energy. At the various phase transitions, the universe was dominated by dark energy. Perhaps the current epoch of acceleration is caused by yet another epoch of

$$\boxed{\text{Episodic Dark Energy}}$$

Test early dark energy by combining CMB Lensing and Galaxy Lensing



Bleem et al (2013)



Van Waerbeke et al (2013)

Quintessence

Einstein Wrong

Episodic Dark Energy

GAP: No good theory to use to generate points

w,w',Growth of Structure, screening mechanism

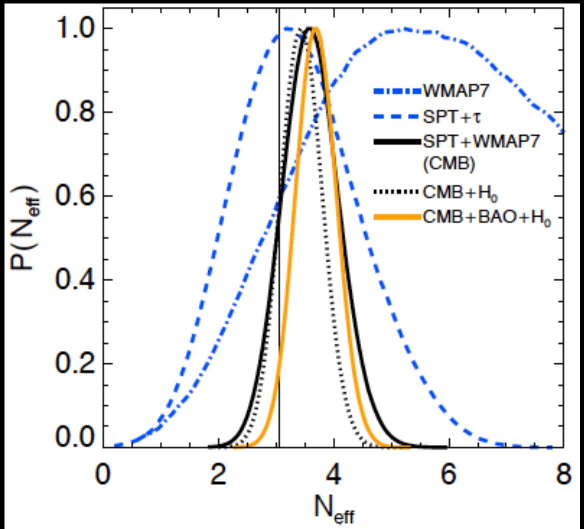
Large scale structure, redshift space distortions, clusters, gravitational lensing, CMB

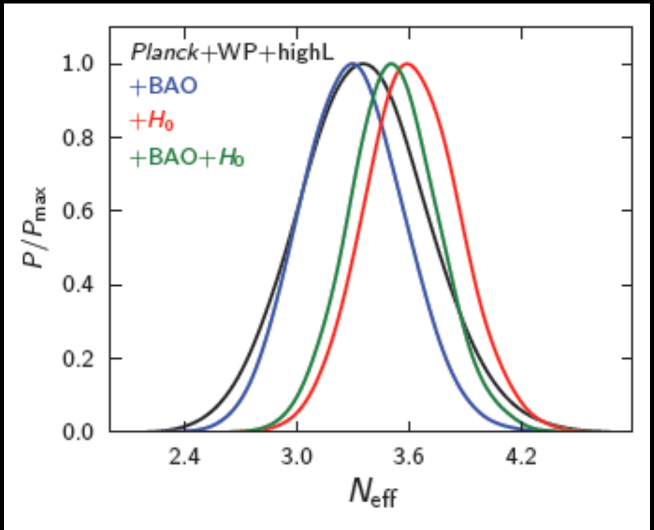
SN

Novel Probes

Key Area of Overlap with Intensity Frontier: Neutrinos

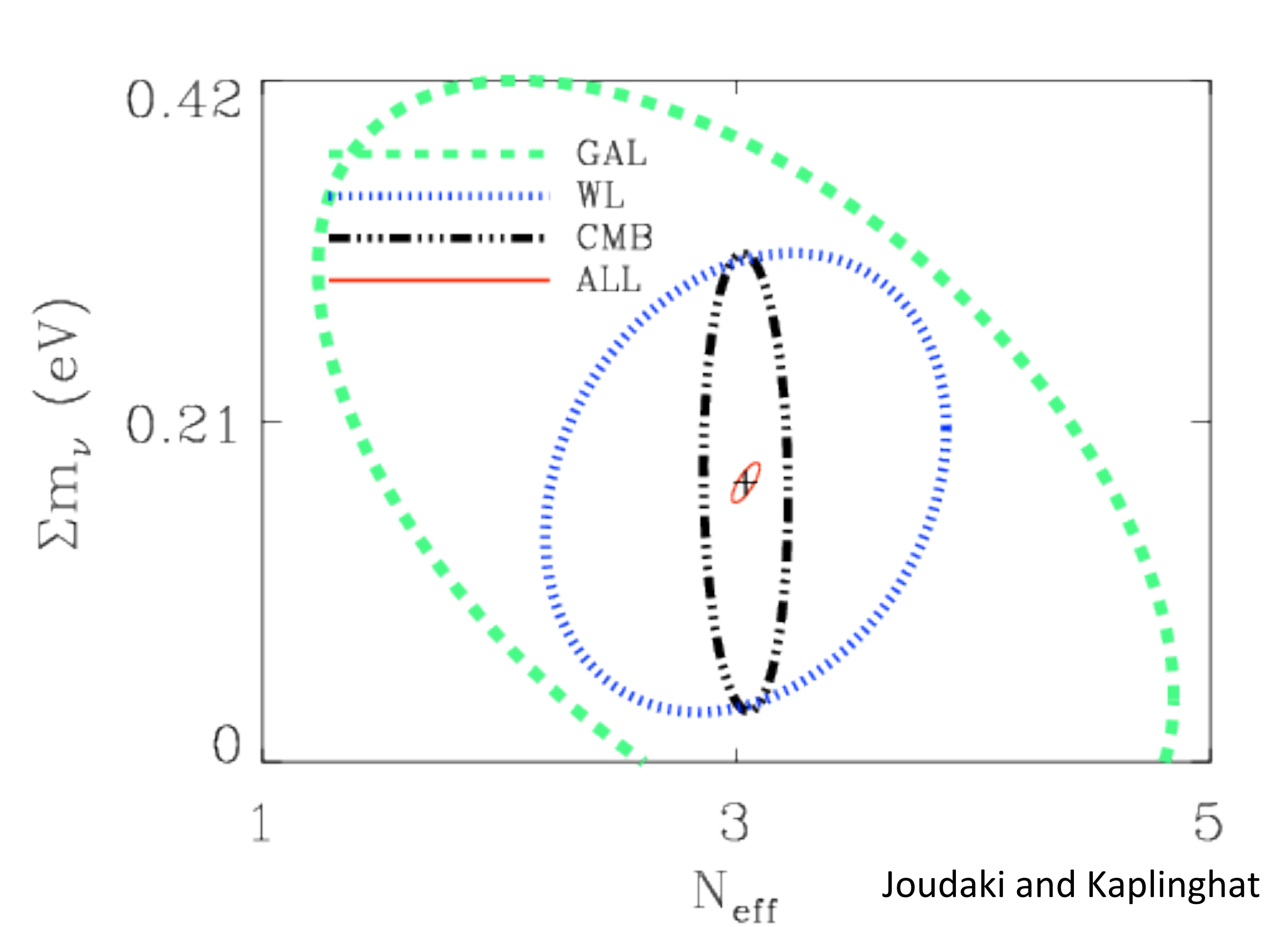
- Indirect detection of cosmic neutrinos
- Pre-Planck hints for sterile neutrinos
- Planck has not yet resolved the issue





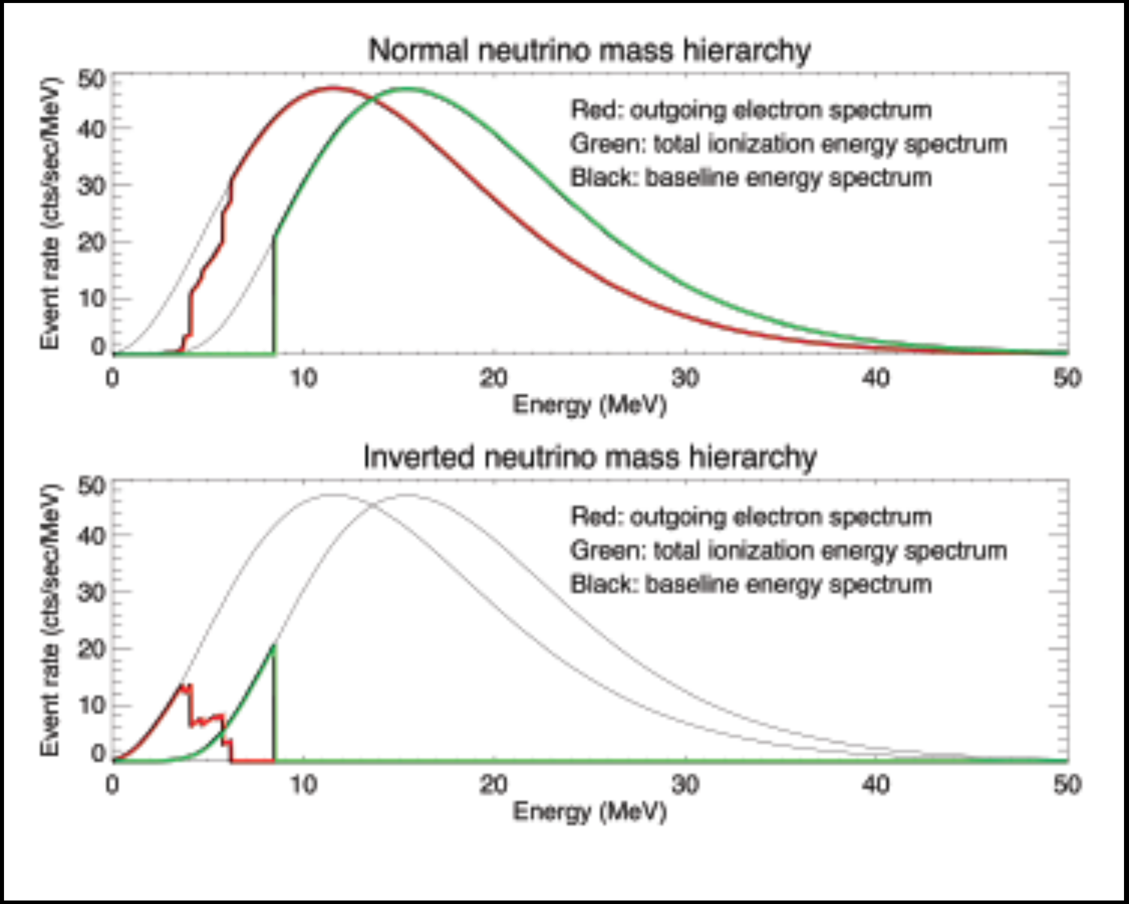
Key Area of Overlap with Intensity Frontier: Neutrinos

- Planck polarization will help
- Cross-correlating LSST with itself and with CMB helps
- Projected 1-sigma constraints: [0.012 eV, 0.058]
- Generation 4 CMB Polarization experiment next decade?



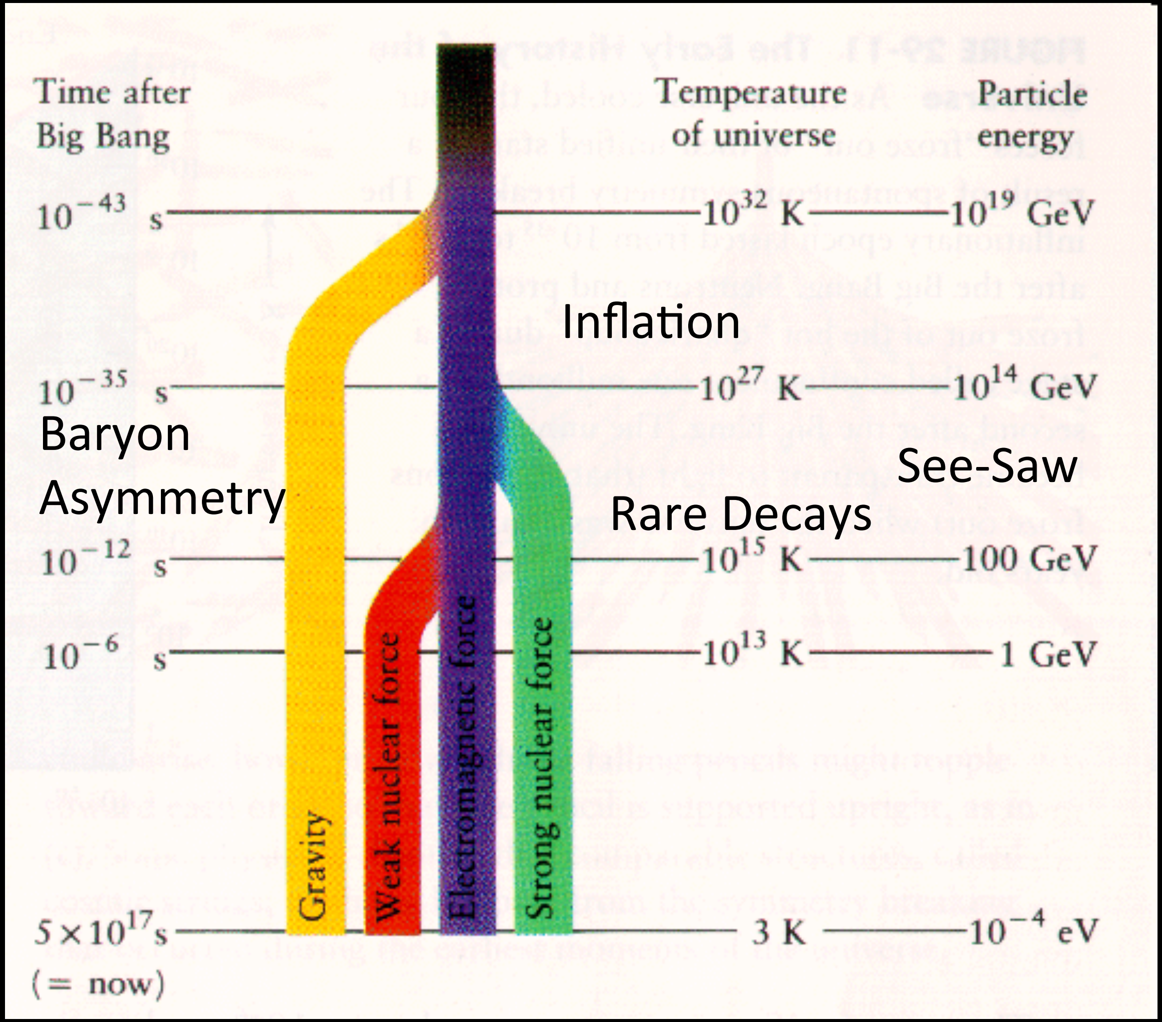
Key Area of Overlap with Intensity Frontier: Neutrinos

- Detection of neutrinos from nearby (10 kpc) Supernova
- 10kT liquid Argon underground
- Hundreds of events (large theory uncertainties)
- Distinguish normal from inverted hierarchy



Cline, Fuller, Lee, Skelton (2012)

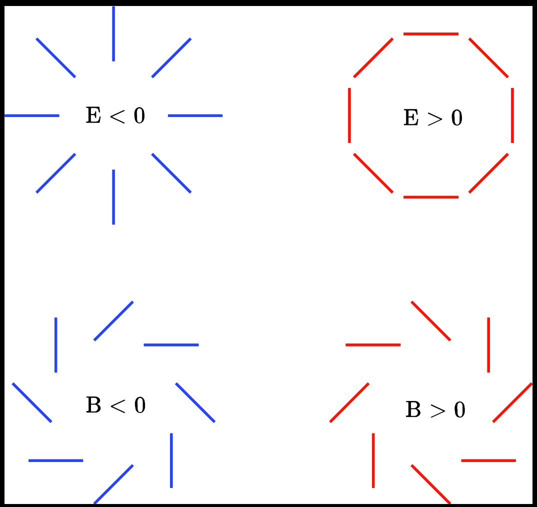
Overlap: Indirect Probes of High Energies



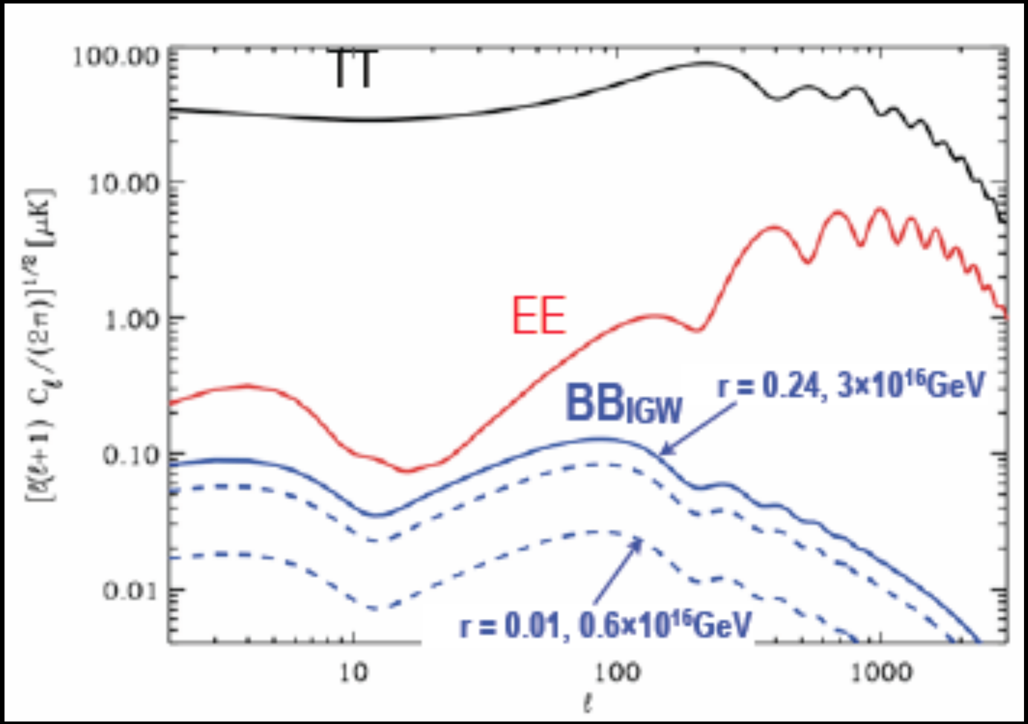
Rieke

Inflation

Passed every observational hurdle to date; model-dependent preditions for primordial gravitational waves, best probed with CMB Polarization



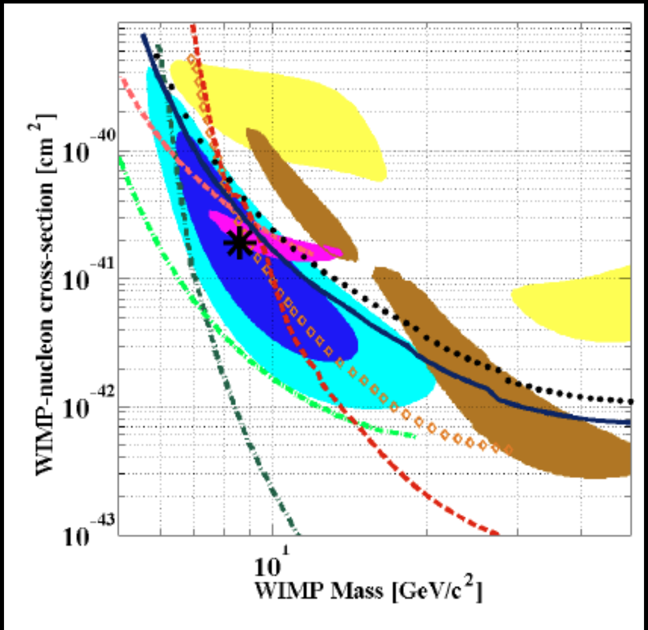
CMB Polarization



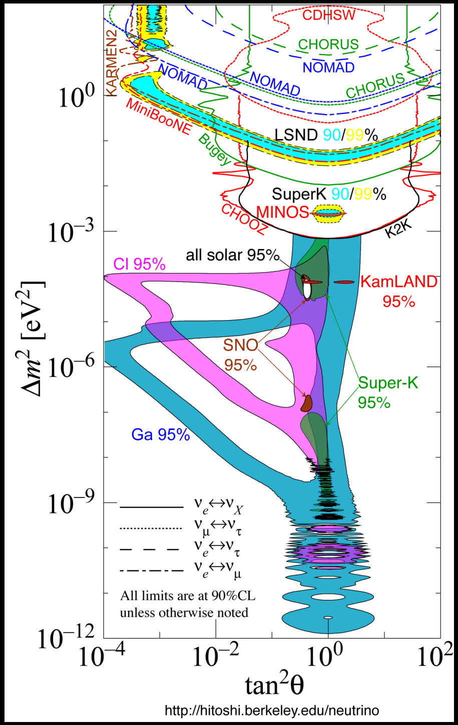
r is ratio of gravitational wave/density perturbations; pins down energy scale of inflation

Baryon Asymmetry of the Universe

Moving from an epoch with no measurements → **several important clues** → diverse program to identify (predictive?) mechanism



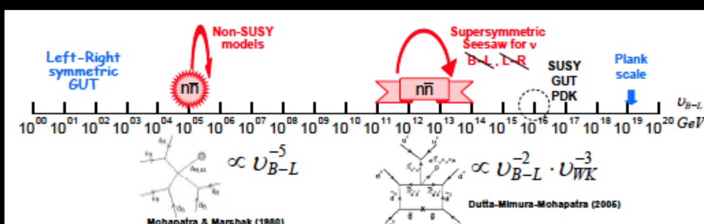
$n_B \sim n_{DM}$:
Asymmetric Dark Matter?



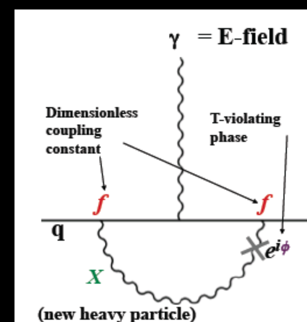
See-saw:
Leptogenesis?

Baryon Asymmetry of the Universe

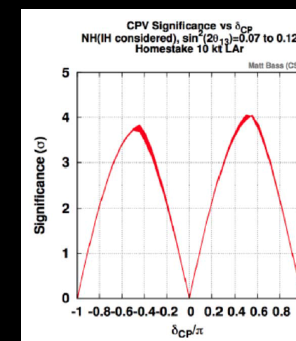
Moving from an epoch with no measurements → several important clues → **diverse program** to identify (predictive?) mechanism



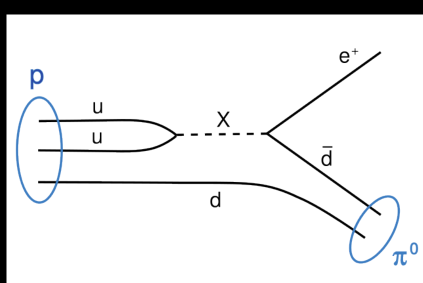
B-violation in n-nbar oscillation



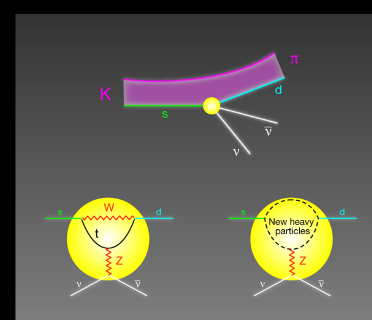
CP violation in EDM



CP violation in neutrino sector



B-violation in Proton decay

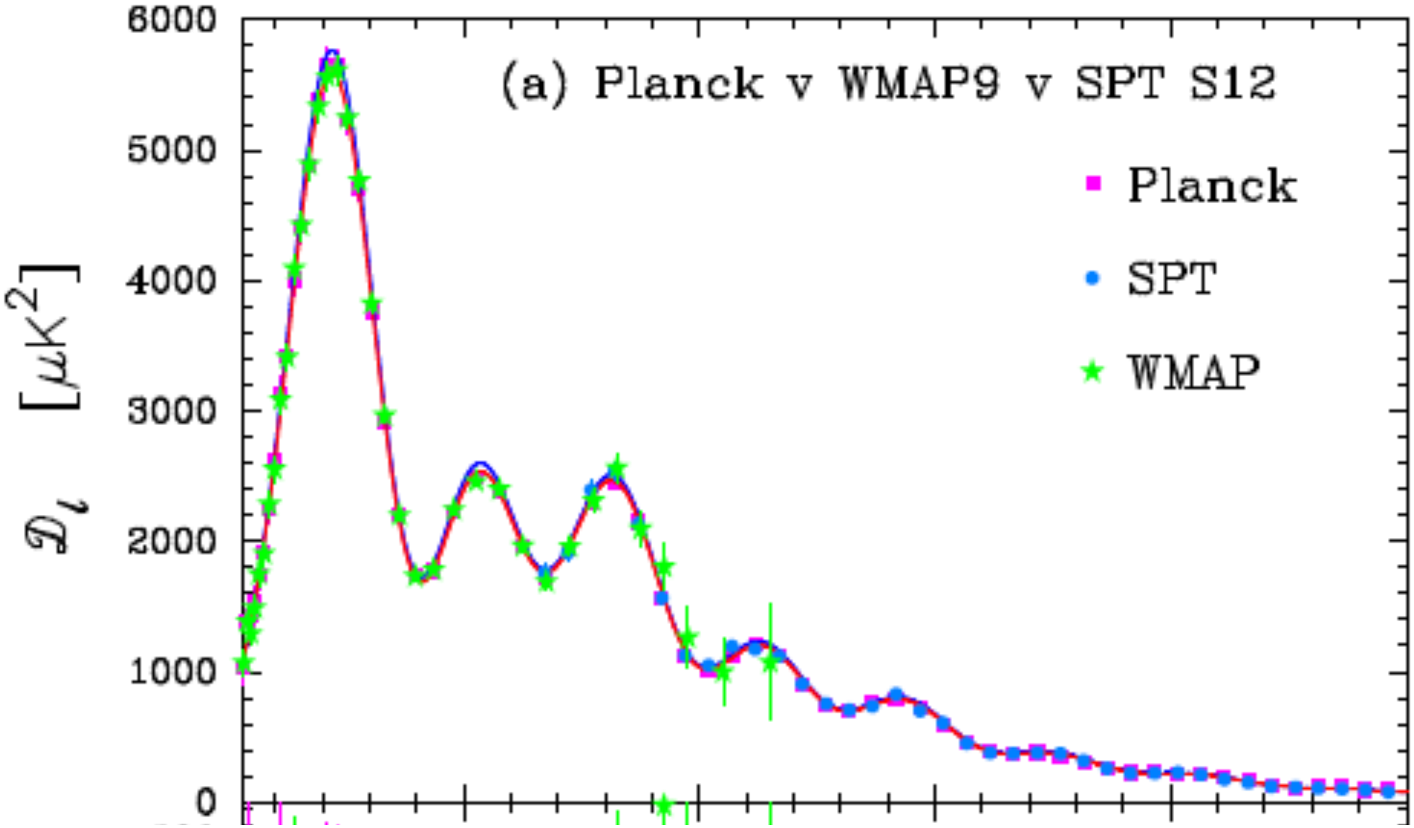


Light anti-baryons in rare decays?

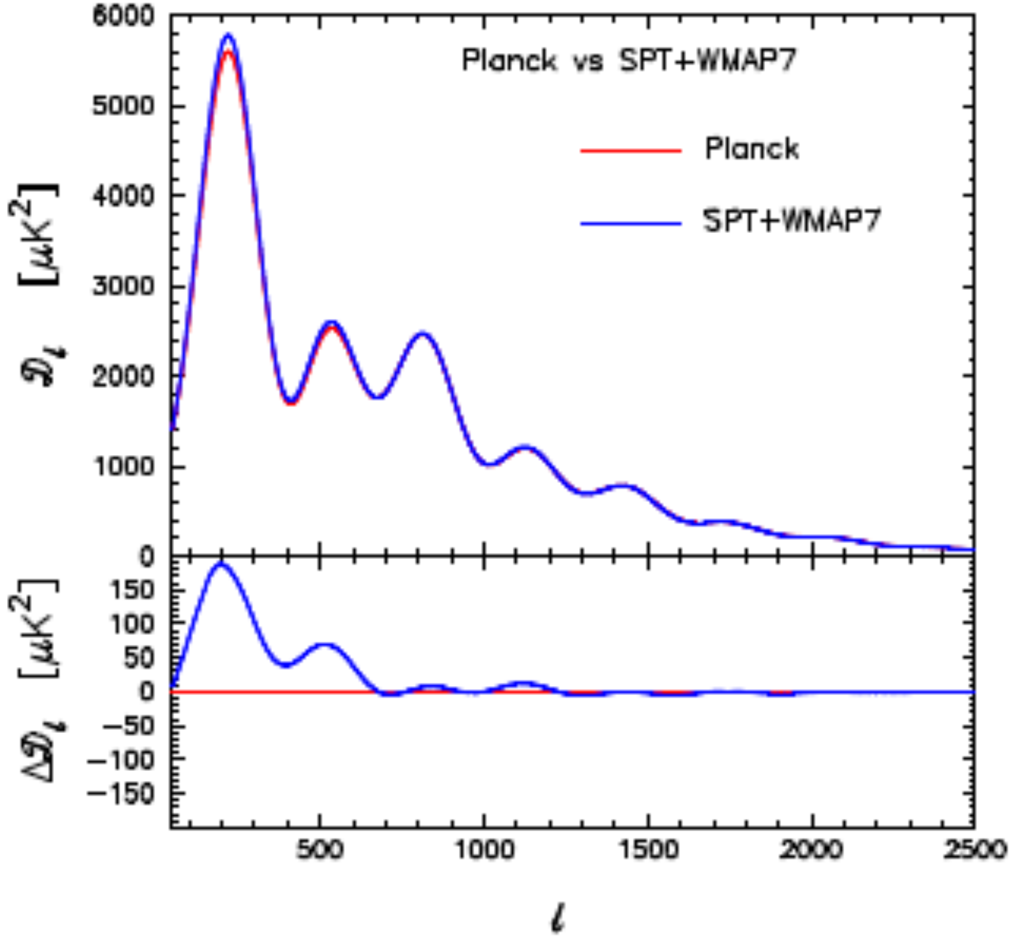
Summary

- Strong dark matter initiatives with complementarity within and between 4 different methods
- Search for cause of cosmic acceleration → interesting ideas (quintessence, modified gravity, episodic dark energy). Testing requires correlating observables
- Common broad physics goals: Neutrinos and Indirect Probes of GUT scale
- Specific Projects:
  - Sterile neutrino in Lab/CMB
  - Sum of neutrino masses/PMNS matrix
  - CMB Polarization
  - Baryon Number (DM, B-violation; CP-violation; rare decays)
  - DM <-> Light particles

Stunning Agreement

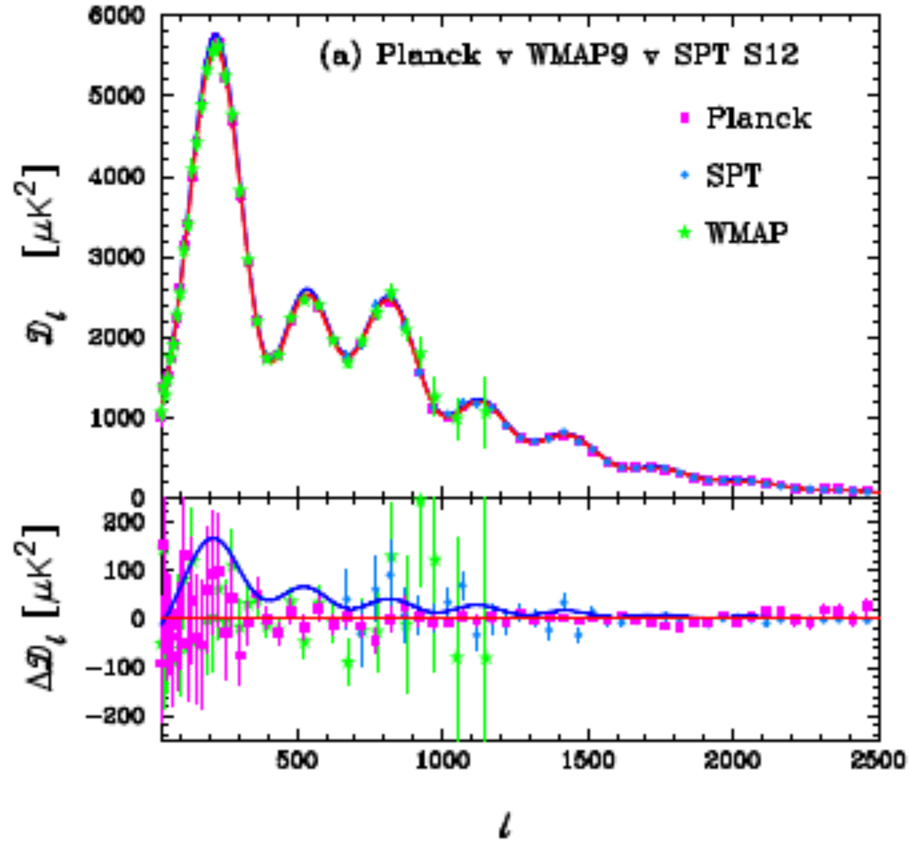


First peak is lower in Planck

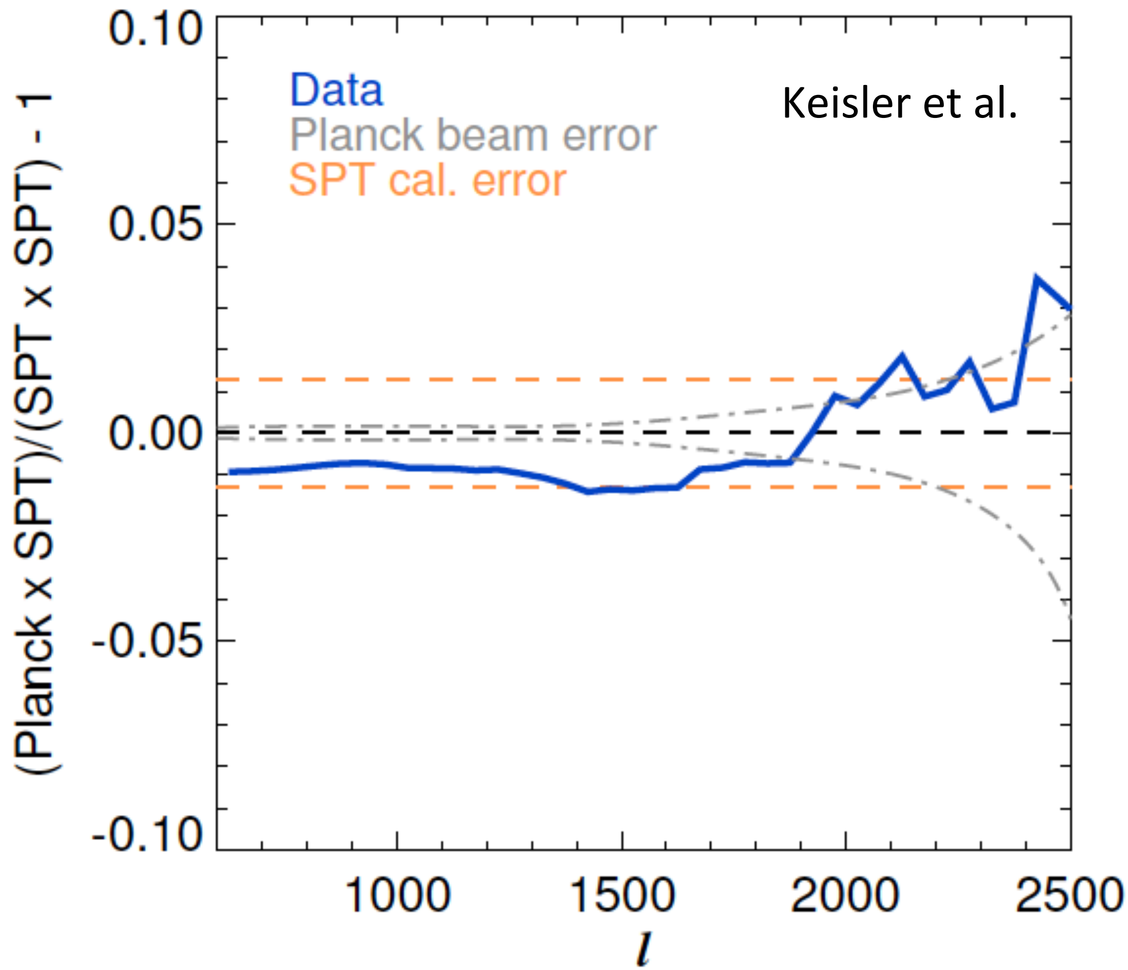


Understanding the difference between Planck and SPT

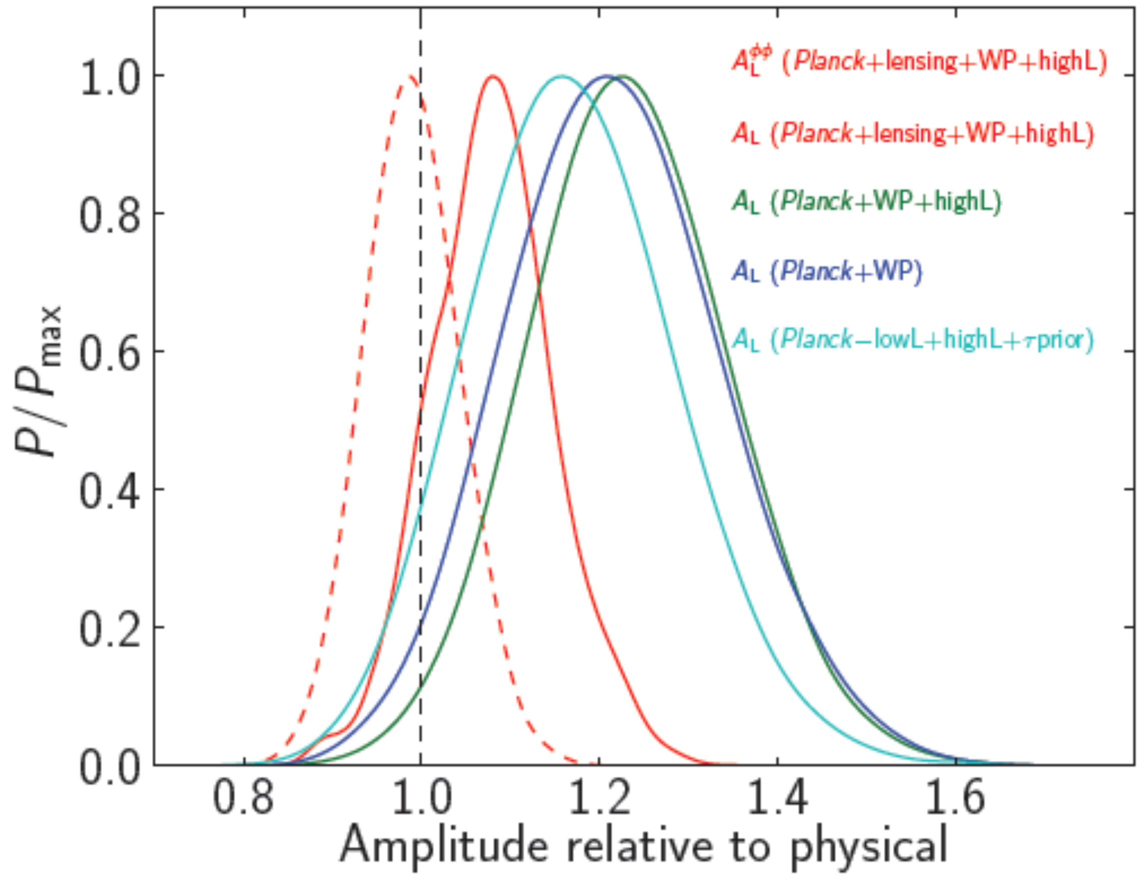
match the rescaled *WMAP*-9 points at $\ell \lesssim 700$. This suggests that the SPT spectrum has a small multipole-dependent bias of about $35\,\mu K^2$ over the multipole range 650–1100.



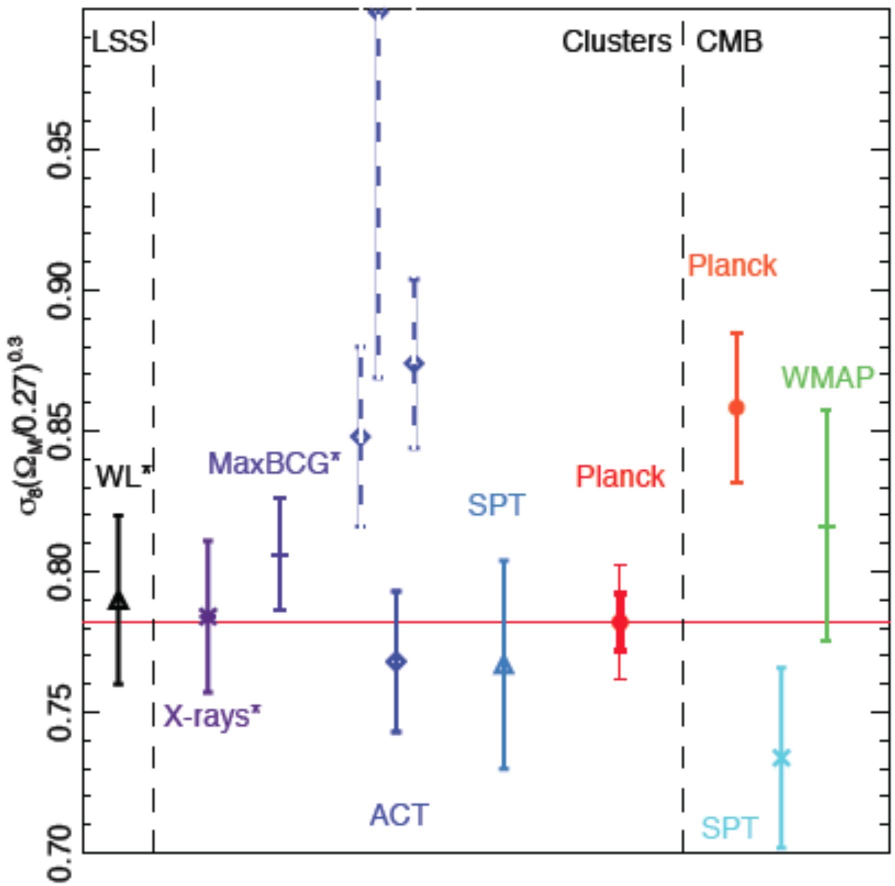
Calibration of SPT?



Smoothing is determined in a given model



Planck temperature results disagree with more than just H_0



Response from KITP Workshop

We have certainly have had many discussions of the implications of the Planck results here at the KITP program
on Primodial Cosmology.
The big picture is that the Planck results are strikingly consistent with single field slow roll inflation.

Aside from reviewing longstanding questions about initial conditions, the new arguments in the paper are concerned with mild constraints on the possible shapes of the potential energy driving inflation, inferred from the improved -- but still statistically weak -- limits on certain parameters in the new data. Assuming these 95 percent confidence level constraints, some of the simplest and theoretically motivated mechanisms for inflation do remain viable, in contrast to the claim of the paper. This includes a number of interesting possibilities, some of which predict an associated gravity wave signature and others of which do not.

Response from KITP

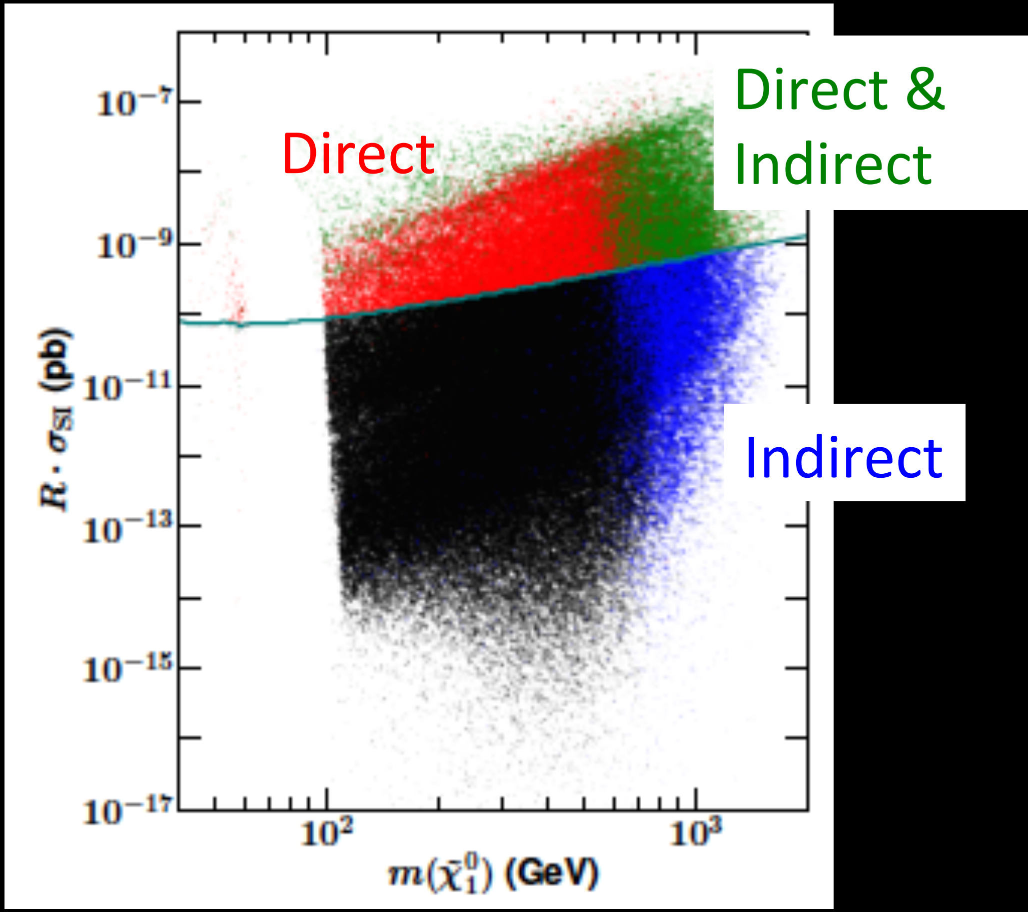
The authors claim that the surviving models are, in their words, `unlikely'. The response in the discussion here was pretty much the opposite. As just one example -- one which the authors themselves agree is theoretically motivated -- we may consider a potential energy which asymptotes to a power of the inflaton field. For these examples, the data mildly favors a power less than quadratic (as discussed explicitly in the Planck inflation paper), a feature of theoretically complete models that I think is reasonable to expect from the point of view of high energy physics. In any case these distinctions are still largely a matter of opinion; with the two parameters under discussion at their current level of significance it is simply impossible to use the data to determine the underlying inflationary mechanism.

Cosmic Frontier (Jonathan Feng and Steve Ritz)

- CF1: WIMP Dark Matter Direct Detection (Cushman, Galbiati, McKinsey, Robertson,Tait)
- CF2: WIMP Dark Matter Indirect Detection (Buckley, Cowen, Profumo)
- CF3: Non-Wimp Dark Matter (Kusenko, Rosenberg)
- CF4: Dark Matter Complementarity (Hooper, Kaplinghat, Matchev)
- CF5: Dark Energy & CMB (Church, Dodelson, Honscheid)
- CF6: Cosmic Particle and Fundamental Physics (Beatty, Nelson, Olinto, Sinnis)

Dark Matter Complementarity

- Well-motivated theory (SUSY) from which to generate models
- Three major techniques cover reasonable fraction of SUSY phase space



http://www.snowmass2013.org/tiki-view_forum.php?forumId=10